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The Wilderness Threats Matrix: A Framework for Assessing Impacts

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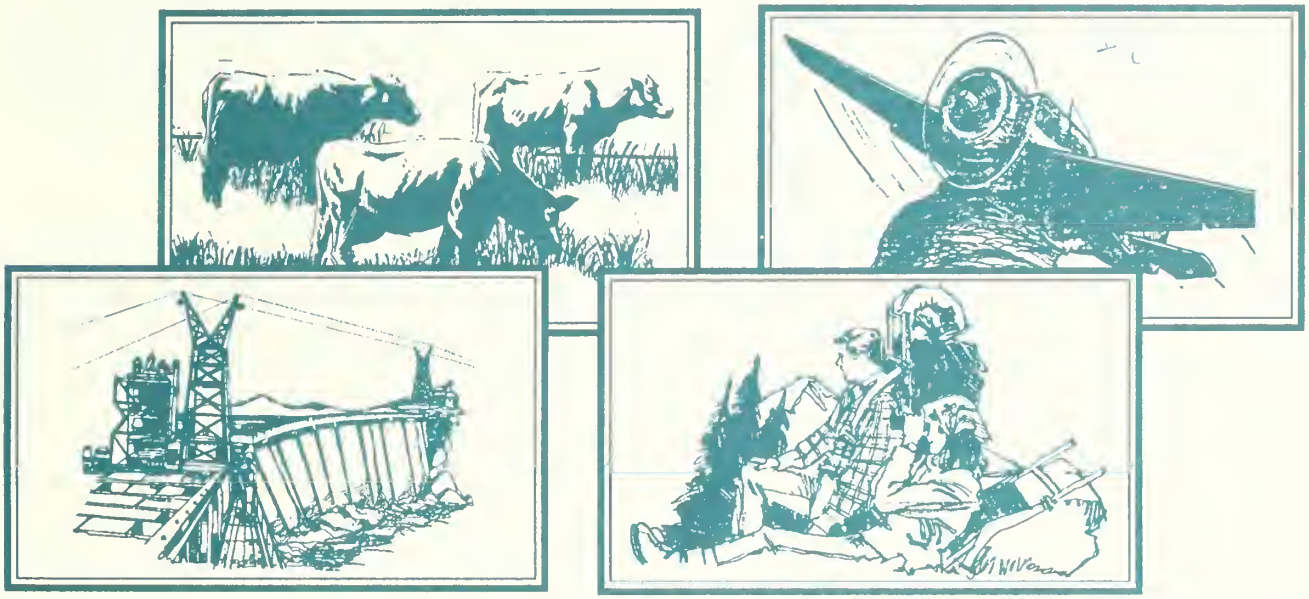

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RESEARCH SUMMARY

This report proposes a comprehensive framework for assessing threats to wilderness. The framework can be depicted as a matrix with potential threats to wilderness as columns and wilderness attributes intended for preservation as rows. Cells in the matrix represent the impacts of each threat on each attribute.

The most generally significant threats to wilderness are recreational use and its management, livestock grazing and its management, mining, fire and its management, exotic species introductions and invasions, water projects, atmospheric pollutants, and practices on adjacent land. The primary wilderness attributes of concern are air, aquatic systems, rocks and landforms, soils, vegetation, animals, ecosystems and landscapes, cultural resources, and opportunities for wilderness experiences.

The threats matrix will help wilderness planners, managers, and researchers. It can be used by planners during the scoping process, in describing the current management situation, in developing assumptions about the future, and in assessing the impacts of alternative management actions. It provides a comprehensive overview of monitoring needs. It can be used to assess research and management priorities for individual wildernesses, regions, and the National Wilderness Preservation System.

The matrix was used to assess threats to wildernesses in the Forest Service's Northern Region (northern Idaho and Montana). The significance of and knowledge about threats were assessed by a team of wilderness experts. The most significant perceived threat was fire and its management; aquatic systems were the wilderness attribute considered to be most threatened. The difference between significance and knowledge was greatest for fire and its management, suggesting that this is the threat most in need of further research. Ecosystems, landscapes, and aquatic systems are the wilderness attributes most in need of further research.

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INTRODUCTION

The 1964 Wilderness Act establishes stringent goals for management of wilderness: preservation of natural conditions and wilderness character, and provision of outstanding opportunities for solitude or a primitive and unconfined type of recreation. In addition, the Act permits a number of specific uses in wilderness that potentially threaten these goals: "Wilderness areas shall be devoted to the public purposes of recreational, scenic, scientific, educational, conservation, and historical use." These uses of wilderness are often referred to as conforming uses. The Act also allows for the continuance of certain "nonconforming" uses—mining on valid claims that existed before 1984, livestock grazing, the establishment and maintenance of reservoirs, administrative facilities, and the control of fire, insects, and diseases. The Act does not specify how to resolve potential conflicts between conforming, nonconforming or administrative uses of wilderness and the preservation of wilderness character. One of the primary responsibilities of wilderness managers is to protect wilderness character from the potential threats these internal uses pose.

Managers' responsibilities become even more daunting in light of the external threats to wilderness. Wildernesses do not exist in a vacuum; they are part of larger landscapes and regions. Wilderness boundaries may be relatively impermeable to chainsaws and mountain bikes, but they are highly permeable to pollutants, migrating animals, exotic species, noise and light, wildfires, insects, and diseases.

Protecting wilderness from these potential threats would be challenging even if managers had a substantial body of scientific knowledge to draw from. Unfortunately, little is known about the impacts of most of these threats. Wilderness research and management have traditionally been focused on problems associated with recreational use. Other potential threats have been largely ignored. Reaching the goal of effective wilderness protection will require knowledge about the entire spectrum of threats to wilderness, including effective ways to monitor these threats and mitigate their impacts. An important step toward this goal is the development of a comprehensive framework of threats to wilderness and their impacts.

This report proposes such a framework—the wilderness threats matrix. This matrix will be a useful tool to wilderness planners, managers, and researchers. It can be used by planners during the scoping process, in describing the current management situation, in developing assumptions about the future, and in assessing the impacts of alternative management actions. It provides a comprehensive overview of monitoring needs. It can be used to assess research priorities, as well as management priorities for individual wildernesses, regions, and the National Wilderness Preservation System. The report includes an example of one of these applications, an assessment of the perceived significance of threats to wilderness in the Forest Service's Northern Region (northern Idaho and Montana).

CONCEPTUAL FRAMEWORK

Managers must be concerned about the *impacts* that potential *threats* have on *attributes* of wilderness character. These three terms are the basis of a conceptual model that can be applied in wilderness. I define threats as human activities or the consequences of human activities that have the potential to change wilderness conditions. These threats can cause impacts to wilderness attributes. Using this terminology, threats are the agents of change, while changes in wilderness conditions are impacts to attributes. This differs from the terminology of Machlis and Tichnell (1985), who apply the term "threat" to both the agent of change and the change itself.

The impacts caused by any single threat will differ depending on the attributes the threat impacts. For example, grazing's impacts on vegetation differ from grazing's impacts on native animals. The impacts of different threats on a single attribute will also differ. For example, the effects of air pollution on vegetation differ from the effects of fire suppression on vegetation. Consequently, managers need to understand the linkages between each significant potential threat and each individual wilderness attribute. Figure 1 displays linkages for eight potentially significant threats to wilderness. Other threats are represented as well. Finally, these potential threats will interact, causing cumulative impacts; the figure recognizes these interactions.

Separating the individual attributes of wilderness character is even more artificial than separating threats, because impacts occur at all spatial and temporal scales, and some of the most significant

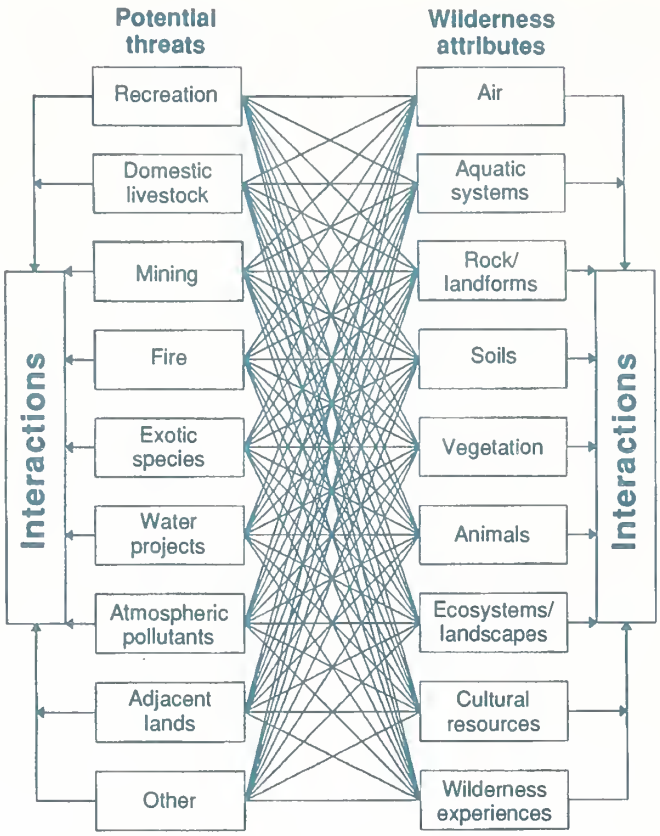

Figure 1—Linkages between potential threats and the wilderness attributes they impact.

impacts affect interactions between attributes (such as plant-soil interactions). I have identified nine individual attributes, along with an interaction box.

The framework for organizing information is most conveniently displayed as a matrix (fig. 2), with the threats forming columns and the attributes forming rows. Each cell consists of the various impacts that each threat causes to each attribute. For simplicity, the interactions among threats are not included in the matrix. Interactions among wilderness attributes are an integral part of the ecosystems/landscapes attribute. In the future, highly significant cumulative threats (such as the combination of fire suppression and grazing) or interactions between attributes (such as those that take place during nutrient cycling) could be included in the matrix.

Threats

The following eight threats are considered the most significant threats to wilderness character. They are arranged from those that are primarily internal to those that are primarily external. These definitions were developed for Northern Region wildernesses but could be modified for wildernesses elsewhere.

Recreation—The threat comes from onsite recreational users, as well as actions taken to manage that use (such as trail construction).

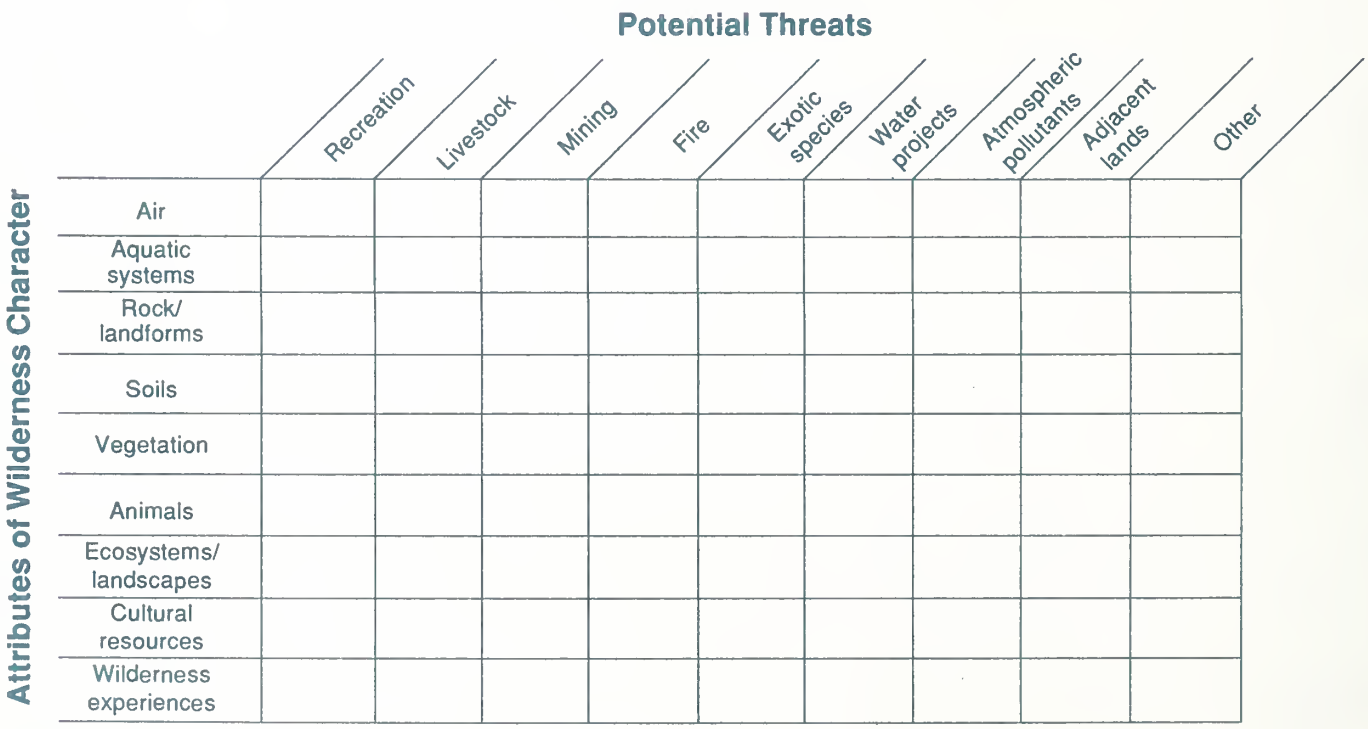

Figure 2—The threats matrix in which each cell represents the impacts that each potential threat has on each wilderness attribute.

Livestock—The threat is the grazing of livestock (primarily cattle and sheep) and their management (fencing, water supplies, and so on).

Mining—Both active and abandoned mines are potential threats.

Fire—In most wildernesses the suppression of natural fires is a primary threat. However, other threats related to fire include human-caused fires in the wilderness, suppression of fires that would otherwise have burned into the wilderness, and impacts caused by fire suppression activities.

Exotic Species—Exotic species have been intentionally and unintentionally introduced into wildernesses. Introduced plants, animals, and diseases are all concerns, as are actions taken to manage them, such as pesticide applications or biological control.

Water Projects—Dams and reservoirs occur in some wildernesses; their existence, operation, and maintenance can cause impacts. Other wildernesses are impacted by water impoundments and diversions upstream from the wilderness.

Atmospheric Pollutants—This threat is from airborne pollutants, usually generated outside the wilderness.

Adjacent Lands—Wilderness is threatened by a wide variety of activities that occur on lands adjacent to (and even some distance from) wilderness. Such activities include resource extraction, water pollution, habitat fragmentation, road development, and urban development.

Other—A long list of other threats could be compiled, including global climate change, scientific use of wilderness, aerial overflights, subsistence use of wilderness, and even other laws and mandates, such as the Clean Air Act, the Endangered Species Act, and the National Historic Preservation Act.

Not all of these will be significant threats to every wilderness. Some of these threats may not apply to certain wildernesses; some threats that haven't been included may apply to other wildernesses.

Attributes of Wilderness Character

Nine important attributes of wilderness character can be differentiated. These should apply to all wildernesses; important interactions also may need to be specified.

Air—This refers to the physical and chemical characteristics of the lower atmosphere, including visibility.

Aquatic Systems—This refers to the physical, chemical, and biological components of aquatic systems.

Rocks/Landforms—This includes mineral, rock, and landform features.

Soils—This refers to the physical, chemical, and biological components of soil systems.

Vegetation—This refers to the composition, structure, and function of terrestrial plants and plant communities, including processes such as succession.

Animals—This refers to the composition, structure, and function of terrestrial animals and animal communities, including processes such as migration.

Ecosystems/Landscapes—This refers to the composition, structure, and function of ecosystems, the interaction between individual attributes. It also refers to characteristics of systems at larger spatial scales, such as landscapes. This complex of attributes might be subdivided for certain purposes.

Cultural Resources—This includes the evidence of previous occupation and use by prehistoric and historic peoples, as well as the current values of indigenous peoples.

Wilderness Experiences—This refers to the opportunities that visitors have to experience solitude, to enjoy a primitive and unconfined type of recreation, and to realize spiritual and educational values. Managers are not responsible for providing these values; they are merely responsible for providing the opportunity.

POTENTIAL APPLICATIONS

The threats matrix has many potential applications to wilderness management. It can be used as a planning tool or to provide the framework for a comprehensive monitoring program. It can be used to assess research priorities or to develop a research program. It can also be used to establish management priorities, both for individual wildernesses and for larger aggregations of wilderness, such as those on a National Forest or in a Forest Service Region.

Planning and Monitoring Applications

An increasing number of wilderness management plans are based on the concept of Limits of Acceptable Change (Stankey and others 1985); these plans devote considerable attention to indicators. Indicators are specific parameters that can be monitored to evaluate the success of management programs. Successful wilderness management primarily entails protecting wilderness conditions (both biophysical and experiential) from threats (human activities). Consequently, indicators need to be developed for the full range of significant threats and potential impacts to wilderness.

Most of the indicators developed to date relate only to the threat posed by recreational use; other important threats are largely neglected. For example, the Bob Marshall Wilderness Limits of Acceptable Change Plan only contains indicators for the effects of recreation

on soils, vegetation, and wilderness experiences. There are no indicators of the impacts of recreation on the six other attributes, or of the impacts of all other threats. Of the 72 cells in the threats matrix, indicators were developed for just three. Until effective indicators are developed for a wider range of potential impacts, Limits of Acceptable Change planning will be severely limited in scope. In future efforts, planners should use the threats matrix as a comprehensive overview of the range of potential wilderness concerns. Then, they should try to develop indicators that reflect the range of significant threats to the specific wilderness.

The threats matrix also may help managers think more comprehensively about monitoring in wilderness. In fact, the matrix has been adopted as part of a conceptual model of wilderness monitoring needs to be used by the four Federal agencies that manage the National Wilderness Preservation System (Cole and others 1993). To protect wilderness, a wide variety of potentially significant impacts need to be monitored. So far, research on wilderness monitoring techniques has been confined primarily to measuring recreation use and its effects on soils, vegetation, and wilderness experiences. Consequently, most wilderness monitoring is confined to these three types of impact—representing less than 5 percent of the full range of potential concerns (3 of the 72 cells). Monitoring techniques for some of the other impacts included in the threats matrix have been developed for lands outside of wilderness, but these techniques need to be modified before they can be readily used by wilderness managers. Entirely new monitoring protocols need to be developed for other types of impacts.

Research Program Applications

The threats matrix also provides an overview of wilderness concerns that can help establish an agenda for wilderness management research. For years, the only federally funded research group devoted solely to wilderness management research has been the Forest Service's Wilderness Management Research unit, U.S. Department of Agriculture. Formerly part of the Intermountain Research Station, this group is now part of the Aldo Leopold Wilderness Research Institute in Missoula, MT. To date, this group has worked primarily on one cell of the matrix, the effects of recreation on wilderness experiences. The group has conducted substantial research on two other cells, recreational impacts on vegetation and soils. The other 95 percent of the threats matrix has been virtually unexamined. Other research groups have developed knowledge about other threats to wilderness (such as fire suppression and air pollution), while conducting research that was not devoted exclusively to wilderness. However, most of the threats and impacts represented by the threats matrix have received no more than minimal research attention.

Research programs need to provide managers with five types of information about each cell in the threats matrix.

Nature of Impacts—What are the impacts of the threat on the attribute? For example, previous research has illustrated that fire suppression can alter vegetation structure (Kilgore and Heinselman 1990) and that recreational use can cause vegetation loss and soil compaction (Cole 1987). Most threats will have many different types of impact on each attribute.

Severity of Impacts and Factors that Influence Severity—Once we understand the types of impact that occur, we need to understand the magnitude of impact and how certain factors cause magnitude to vary. For example, research suggests that vegetation loss caused by recreation can range from no perceptible loss to complete denudation. Soil compaction caused by recreation ranges from no perceptible compaction to a severalfold increase. The amount of vegetation loss and soil compaction is a function of factors such as the amount of use, type of use, season of use, soil moisture, and the durability of the vegetation. Much has been learned about the influence of these factors (Cole 1987; Kuss and others 1990). This knowledge is important to managers because they can control the severity of impacts by manipulating these factors.

Significance of Impacts—Knowledge about the nature and severity of impacts can help managers understand the significance of these impacts. Some impacts—such as the effect of exotic species on air quality—are likely to be insignificant. Others—such as the effects of fire suppression on vegetation—are highly significant because they influence the composition, structure, and function of ecosystems for long periods over vast tracts of land. Specific criteria for judging significance are not well defined; they require integrating ecological concerns with human values. However, judgments about significance are critical to setting priorities related to threats and impacts.

Effectiveness of Management Strategies—Numerous alternative strategies have been implemented in attempts to control the impacts of different threats. Understanding the factors that influence the severity of impacts can help identify strategies that are likely to be effective. Once these strategies have been implemented, research should attempt to evaluate their success.

Indicators and Monitoring Techniques—As discussed previously, indicators need to be developed for threats that are likely to have significant impacts on wilderness. Information about the nature of impacts, along with an assessment of their significance, can help identify important indicators. In addition, researchers need to develop monitoring protocols for likely indicators and test these protocols in the field.

This should allow managers to monitor the most significant threats to wilderness conditions cost effectively.

Individual Wilderness Applications

The threats matrix should also be used to establish management priorities for individual wildernesses. Wilderness managers need to gather information about the extent and severity of threats to their wilderness and the impacts of these threats. This information can be used, along with research information about the nature of impacts and public concern, to assess the relative significance of threats and impacts. The application to Northern Region wilderness that follows illustrates how this can be done based on group judgment.

Highly significant threats and impacts should be high priorities for management. These priority items should be among the issues and concerns that drive management plans. They should be the focus of monitoring efforts and other wilderness management programs. There may be very little information about threats or impacts that are thought to be highly significant. A critical need exists to gather information about the extent and severity of these impacts.

The cells in the threats matrix can also be used as categories for compiling and accessing information about impacts to wilderness. Separate files—either electronic or paper—can be kept for each combination of threat and attribute. Literature about these impacts, monitoring data, and experience with mitigation can be stored in these files.

APPLICATION TO NORTHERN REGION WILDERNESS

To illustrate one application of the threats matrix, I conducted an assessment of threats to and impacts on the 15 wildernesses in the Forest Service's Northern Region. These wildernesses encompass more than 5 million acres (fig. 3). Each threat is briefly described, its most obvious impacts are mentioned, and a few basic references are provided. Finally, the significance of and current knowledge about the threats are evaluated.

Evaluation

Members of the Northern Region's Wilderness Interdisciplinary Team were given the threats matrix (fig. 2) and asked to evaluate the significance of and knowledge about the actual or foreseeable impacts each potential threat has had on each wilderness attribute. The criteria used to derive significance ratings were (1) extent and (2) importance. Extent refers to how many wildernesses experience the impact and the proportion of the wilderness that is impacted. This part of the rating is relatively objective.

Importance is more subjective and was based on an assessment of the likely longevity of the impact, the rarity of the attributes being impacted, and the extent

Figure 3—Wildernesses in the Forest Service's Northern Region.

to which ecosystem function is altered. Ratings were on a scale from 1 (low significance) to 5 (high significance). Highly important but localized impacts and very extensive but relatively unimportant impacts would be rated 3. An impact that is both moderately widespread and moderately important would also be rated 3. An impact that is unimportant would be rated 1 regardless of its extent.

Knowledge was also rated on a scale from 1 (little knowledge) to 5 (much knowledge). The types of knowledge under consideration were the nature, significance, extent, and severity of impacts. Knowledge about appropriate management or monitoring of these impacts was not considered. This is an important distinction because some impacts are quite well understood, although there is no cost-effective way to monitor them.

The criteria used to derive knowledge ratings were knowledge of cause-and-effect relationships and empirical data about the extent and severity of impacts. For example, if cause-and-effect relationships are obvious from common sense, but there is little data on extent or severity, the rating would be 3. Ratings are relative to each other and assess how much is known—not how much more needs to be learned. Ratings of 5 mean that cause-and-effect relationships are well understood with substantial empirical data on the impacts. A rating of 5 does not mean that much more could not be learned. Knowledge ratings were not assessed for impacts considered insignificant (those cells given a significance rating of 1).

Impacts of Recreation and Its Management

Recreational use of wilderness affects physical and biological resources (Hammitt and Cole 1987; Kuss and others 1990). Aquatic systems are affected when trails and other denuded areas erode, increasing sediment loads and turbidity, when waters are polluted by wastes from humans or livestock, and when fish are planted in fishless lakes. Soil and vegetation are severely affected along trails, in campsites, grazed meadows, and other areas where use is concentrated. Soils are physically, biologically, and chemically altered and, in some cases, eroded away because of impacts associated with recreation. Plants are injured and killed, reducing vegetation abundance and changing the community's composition. Animals are affected when recreationists disturb their habitat, approach them too closely, or kill them.

Recreational use can also result in conflict between wilderness visitors and diminish perceptions of solitude (Manning 1985). These impacts reduce opportunities for high quality wilderness experiences. Attempts to manage recreational use also cause impacts. Use restrictions can reduce access to the wilderness and diminish the "unconfined" nature of the recreational experience. Development of facilities to reduce resource damage can diminish the "primitive" nature of the experience. Facility construction, particularly trail construction, can also impact physical and biological resources.

These impacts occur throughout Northern Region wildernesses, although they are most severe in the more heavily used portions of the most popular wildernesses (such as lake basins in the Absaroka-Beartooth or the Cabinet Mountains and river corridors in Hells Canyon or in the Frank Church-River of No Return Wilderness). The most significant perceived impacts of recreation use in Northern Region wilderness are to aquatic systems, animals, and wilderness experience opportunities (fig. 4). Impacts on vegetation, soils, and cultural resources can be locally severe, but are of limited significance at the landscape scale. Our knowledge is greatest about impacts to vegetation, soils, and wilderness experiences. The greatest discrepancy between significance and knowledge is for impacts to aquatic systems and animals. Additional knowledge is needed for all types of recreational impact, but these two topics are particularly critical research needs.

Impacts of Livestock Grazing and Its Management

Livestock grazing is allowed in wilderness if it was an established use before designation. Moreover, guidelines contained in the Colorado Wilderness Act (P.L. 96-560) make it clear that Congress considers

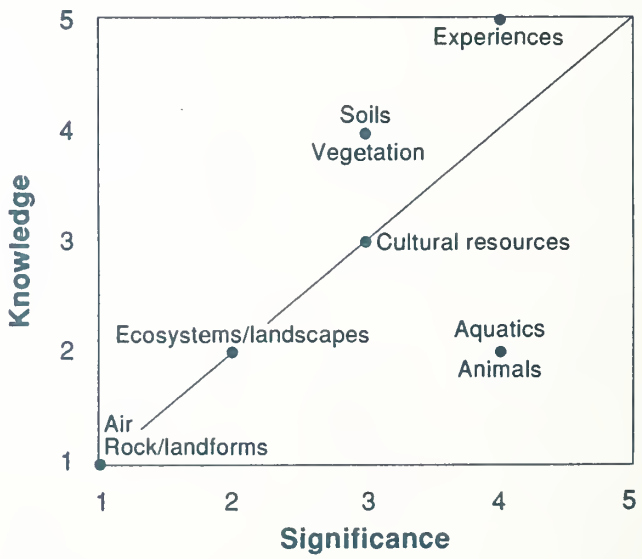

Figure 4—The significance of recreational impacts on each wilderness attribute and knowledge about the impacts. Attributes below the diagonal line of equal significance and knowledge ratings are the ones most in need of further research.

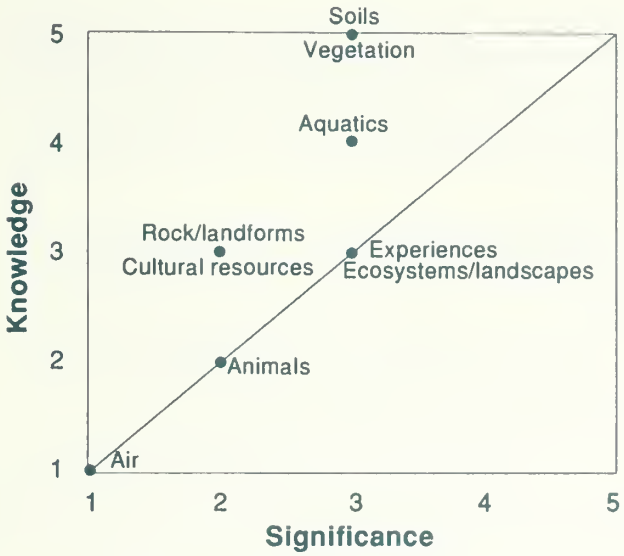

Figure 5—The significance of livestock grazing impacts on each wilderness attribute and knowledge about the impacts. Attributes on the diagonal line of equal significance and knowledge ratings are the ones most in need of further research.

grazing in wilderness to be appropriate and intends that it be maintained. However, the trampling and grazing of sheep and cattle do cause impacts on physical and biological conditions in wilderness (Vallentine 1990). The physical, biological, and chemical characteristics of soils can be altered by grazing, as can the abundance and composition of vegetation. Aquatic systems and channel morphology can also be changed (Platts 1981). Visitors can be displeased when they encounter livestock or the evidence of livestock grazing. Fences, line cabins, water wells, stock tanks, and similar facilities also impact physical resources, wilderness, and experiences, as does the use of motorized equipment to maintain these facilities.

In 1991, about 14,000 animal-unit-months of grazing were permitted in Northern Region wilderness. Only six wildernesses had significant amounts of grazing (Absaroka-Beartooth, Gospel Hump, Lee Metcalf, Gates of the Mountains, Hells Canyon, and Anaconda-Pintlar). Given the limited grazing, significance ratings for grazing impacts were moderate on a regionwide basis (fig. 5). For individual wildernesses with livestock grazing, ratings would be much higher. Most attributes—other than air and, perhaps, animals and cultural resources—are significantly affected by grazing, where it occurs. For example, the vegetation of most Northern Region wilderness evolved without much grazing pressure from large ungulates. Consequently, much of the vegetation (such as perennial bunchgrasses) is intolerant of heavy and repeated defoliation.

Our knowledge about the effects of grazing is substantial, but virtually no studies have been conducted in wilderness. Additional knowledge is needed most for impacts to ecosystems/landscapes, wilderness experience opportunities, and animals. Wilderness management could profit greatly from the application of range management experience to the unique characteristics of wilderness.

Impacts of Mining

About 1,200 mining claims have been recorded in 12 Northern Region wildernesses. So far, however, claims have been validated only in the Cabinet Mountains Wilderness, where two mines are in the permitting stage. Past and present impacts, therefore, have been highly localized. The future is less clear, depending on the number of recorded claims determined to be valid and the type of operation used at each valid claim. Impacts can be substantial in the localized areas where mining activity reaches the exploration phase. They can be severe where development and production occur. Moreover, valid claims are real property that convey rights of access and can become private inholdings.

The impacts of mining can be the most intense impacts in wilderness. Vegetation and soils are likely to be highly disturbed at the mine site, and aquatic systems can be altered by acid drainage from mines or by chemicals used in the mining process, such as nitrates. However, in the Northern Region, mining impacts are now the most geographically localized of all significant threats to wilderness. Given this localized impact, the most significant impacts are likely to be to aquatic systems (fig. 6), because these impacts can extend long distances from the source of disturbance. Our knowledge about mining effects is substantial, particularly regarding impacts to soils and aquatic systems. Additional knowledge is needed most for impacts to ecosystems/landscapes, animals, and wilderness experience opportunities.

Impacts of Fire and Its Management

Fire is an important natural component of most wilderness ecosystems (Wright and Bailey 1982). Suppression of natural fire over the past half century or more has had substantial effects on many of these wilderness ecosystems (Kilgore and Heinselman 1990). Suppression of natural fires that ignited within wilderness and of natural fires that would have burned into wilderness are both of concern. Fire suppression activities generally decrease the frequency of fires and increase their magnitude. Larger, more intense fires will cause more pronounced nutrient and sediment flushes through aquatic systems, as well as more catastrophic changes in vegetation structure and composition, greater losses of soil organic horizons, and increased

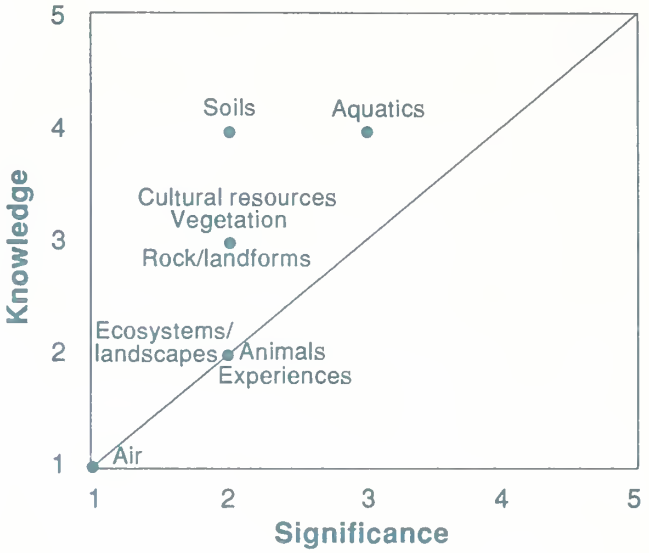

Figure 6—The significance of the impacts of mining on each wilderness attribute and knowledge about the impacts. Attributes on the diagonal line of equal significance and knowledge ratings are the ones most in need of further research.

losses of nitrogen through volatilization. Periods between fires will be characterized by excessive organic fuel buildup, incomplete decomposition of biomass, and inhibition of nutrient cycling (Kilgore and Heinselman 1990). In addition, human-caused fires—either ignited in or burning into wilderness—can be considered adverse impacts, as can disturbances caused by firefighting.

The impacts of altering natural fire regimes are highly significant because fire plays such a critical role in the functioning of most ecosystems and because its effects are so widespread. This assessment suggests that the most significant impacts of fire and its management in Northern Region wilderness are to soils, vegetation, ecosystems, and landscapes (fig. 7). Our knowledge about fire effects is substantial, particularly regarding impacts to vegetation, soils, animals, aquatic systems, ecosystems, and landscapes. The greatest discrepancy between significance and knowledge is for impacts to soils, ecosystems/landscapes and wilderness experience opportunities. Fortunately, research on wilderness fire has received considerable attention in the past; hopefully, this attention will continue in the future.

Impacts of Exotic Species Introductions and Invasions

Many exotic species have been purposely introduced or have invaded the Northern Rocky Mountains since European settlement began in earnest in the late 19th century. A wide variety of exotic species now inhabit wildernesses, including plants from fungi to vascular plants, and aquatic and terrestrial vertebrates and invertebrates. Among the most significant introductions are:

- The white pine blister rust fungus, which is seriously affecting whitebark pine at high elevations throughout the Northern Region (Hoff and Hagle 1990).
- A wide variety of vascular plants from noxious weeds like spotted knapweed to forage plants like timothy (Tyser and Worley 1992).
- Exotic fish like some trout species (Luecke 1990).

The geographic extent of these introductions varies widely from the broadly distributed white pine blister rust, to the common but localized vascular plant introductions, to the highly localized fish introductions. Although fish introductions may originally have been confined to a few lakes and streams, these introductions may now have altered a substantial proportion of aquatic systems in wilderness.

The impacts of exotic introductions are less dramatic in Northern Region wilderness than perhaps in any other part of the United States, outside of Alaska. This reflects the harsh climatic conditions of the high-elevation mountain wildernesses, their large size, and the relatively low level of disturbance to surrounding lands. Nevertheless, some impacts are significant,

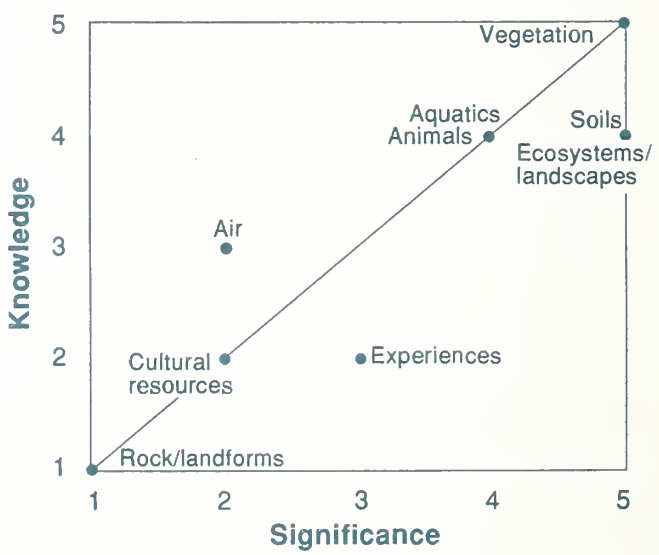

Figure 7—The significance of fire-related impacts on each wilderness attribute and knowledge about the impacts. Attributes below the diagonal line of equal significance and knowledge ratings are the ones most in need of further research.

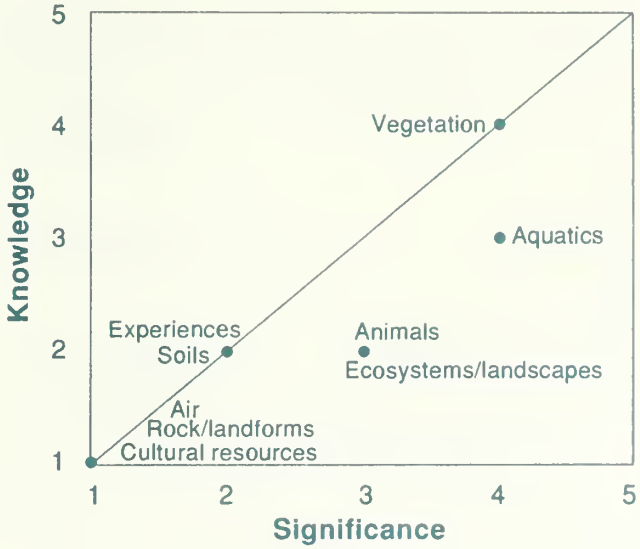

Figure 8—The significance of impacts caused by exotic species introductions on each wilderness attribute and knowledge about the impacts. Attributes below the diagonal line of equal significance and knowledge ratings are the ones most in need of further research.

particularly to aquatic systems and vegetation (fig. 8), and introductions could easily increase in the future. Our knowledge about exotic introductions is meager, except for the impacts of exotic plants on vegetation; even here, much more needs to be learned. The greatest discrepancy between significance and knowledge is for impacts to aquatic systems, ecosystems/landscapes, and animals.

Impacts of Water Projects

Wilderness conditions are affected by dams and water diversions within three wildernesses—the Selway-Bitterroot, Absaroka-Beartooth, and Rattlesnake. These dams raise the level of lakes and keep those levels more constant. They also diminish peak stream flows in early summer and prolong moderate flows through the summer. Of more significance is the effect of upstream dams and water diversions along the Snake River in the Hells Canyon Wilderness. Water projects can alter a stream's water temperatures, sediment loads, and chemical and biological characteristics as well as adjacent soils and vegetation (Ward and Sanford 1987). The headwaters of the Salmon River, which flows through the Frank Church-River of No Return and Gospel Hump Wildernesses are also outside of the wildernesses. These upstream waters are used extensively for irrigation, but there are no major water impoundments. Pollution of upstream waters can also affect wildernesses. Finally, all wildernesses that contain anadromous fish are affected by downstream dams that make migration to and from the ocean difficult (Nehlsen and others 1991).

Most of these impacts are highly localized and occur in only a small number of wildernesses in the Northern Region. However, where they do occur, these impacts can be highly significant. They can alter riparian habitat and impact rare and threatened taxa (such as certain races of salmonid fish). In other parts of the country, where headwater streams more commonly originate outside of wilderness, these impacts are likely to be much more significant. The most significant impacts of water projects in Northern Region wilderness have probably been to aquatic ecosystems and to streamside vegetation (fig. 9). Knowledge about these impacts is substantial, given the significance of the impacts. Additional knowledge is needed most for impacts to vegetation and ecosystems/landscapes.

Impacts of Atmospheric Pollutants

Both local and distant sources of atmospheric pollution can affect wilderness when polluted air enters wilderness. Even though Northern Region wildernesses are far from major pollution sources, they lie downwind of major industrialized and urban areas along the Pacific coast. Important pollutants include sulfur oxides (emitted during combustion of fossil fuels, smelting of ores, manufacturing of steel, and refining of petroleum), nitrogen oxides (emitted during combustion, primarily by vehicles), and volatile organic compounds (also emitted primarily by vehicles). Secondary pollutants,

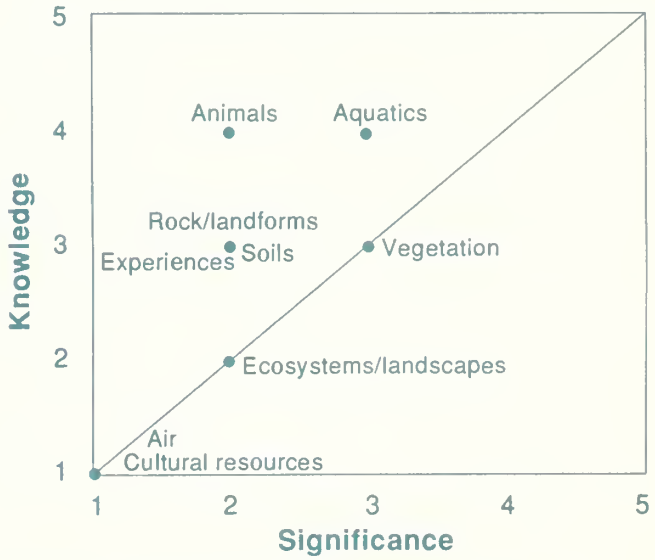

Figure 9—The significance of impacts caused by water projects on each wilderness attribute and knowledge about the impacts. Attributes on the diagonal line of equal significance and knowledge ratings are the ones most in need of further research.

such as ozone and fine particulate matter, form when primary pollutants are transformed in the atmosphere. Pollutants can be transferred to the ground by dry and wet deposition, as well as by contact with low-lying clouds.

The potential impacts of atmospheric pollutants are great because they are so broadly dispersed and capable of altering the most basic functions of ecosystems (Schreiber and Newman 1987). Impacts include reductions in visibility and inputs to aquatic systems that change water chemistry, affecting the aquatic biota. Deposition on plants can injure them directly, but the most pervasive impacts might be the indirect effects of pollutants on soils, such as reduced nutrient availability, increased solubility of toxic metals, and reduced mycorrhizal development (Grigal 1988).

Northern Region wildernesses are less severely impacted than wildernesses in other parts of the country because there are relatively few significant local sources of pollution. Nonetheless, impacts to air, soils, vegetation, aquatic systems, and ecosystems/landscapes can be quite significant (fig. 10). Fortunately, the effects of air pollution have been studied extensively, and a number of studies have begun in wilderness. The greatest discrepancy between significance and knowledge is for impacts to ecosystems/landscapes, soils, and vegetation.

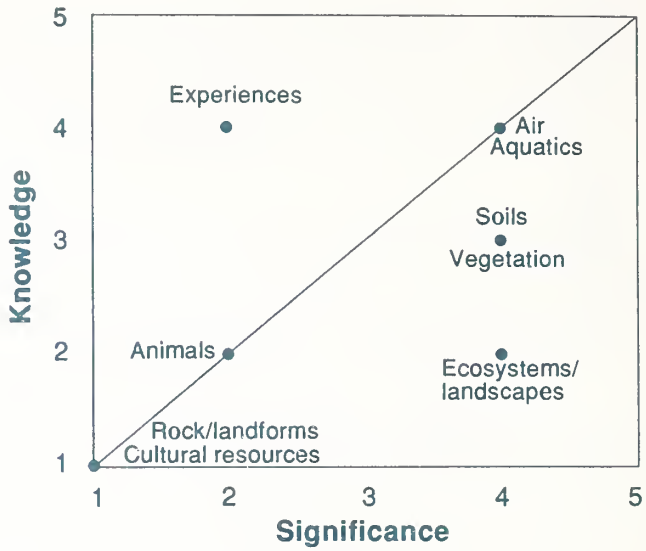

Figure 10—The significance of impacts caused by atmospheric pollutants on each wilderness attribute and knowledge about the impacts. Attributes below the diagonal line of equal significance and knowledge ratings are the ones most in need of further research.

Impacts of Practices on Adjacent Lands

Practices on adjacent lands that affect wilderness include several threats that have already been discussed, such as emission of atmospheric pollutants, water projects, and fire management. Other activities on adjacent lands that can cause impacts include timber cutting, road construction, and urban development. These can pollute downstream waters, introduce exotic species, and adversely affect migratory animals (Glenn and Nudds 1989). These impacts can be particularly severe in wildernesses downstream from developed lands (Hells Canyon, Selway-Bitterroot, Frank Church-River of No Return, and Gospel Hump), as well as those that are relatively small. Although the Northern Region contains several of the largest blocks of wilderness in the United States, six wildernesses are smaller than 100,000 acres, or are fragmented with the fragments smaller than 100,000 acres. For these smaller wildernesses, particularly, wilderness must be managed as part of a larger landscape (Harris 1984). Fragmentation and development of the larger landscape affects large-scale ecological processes, flows of energy and materials, and disturbance regimes (Schonewald-Cox and Buechner 1992).

The impacts of practices on adjacent lands are quite substantial, particularly to animals, ecosystems/landscapes, and wilderness experiences (fig. 11). These external impacts are probably less severe in Northern Region wilderness than anywhere else in the United States outside of Alaska. This reflects the relative lack of development and low population in the Northern Rockies. In other parts of the country, these external impacts are likely to be much more significant.

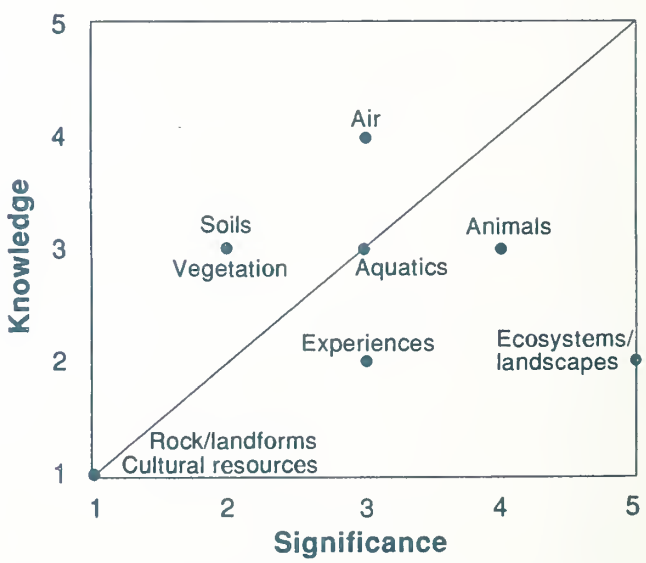

Figure 11—The significance of impacts caused by practices on adjacent lands on each wilderness attribute and knowledge about the impacts. Attributes below the diagonal line of equal significance and knowledge ratings are the ones most in need of further research.

Our knowledge about impacts of practices on adjacent lands is sparse, particularly for impacts to ecosystems/landscapes, wilderness experiences, and to a lesser extent, animals. More research on these impacts is clearly needed.

Significance of Threats to Northern Region Wilderness

This analysis identifies those threats to Northern Region wilderness that are considered to be most significant and the wilderness attributes that are considered to be most threatened (fig. 12). This knowledge can help set regional priorities for wilderness management. The significance of each potential threat depends on the wilderness attribute being considered. For example, recreational use is a significant threat to wilderness experience opportunities but has little effect on air. Each potential threat is the most significant threat to at least one attribute. Fire and its management was considered the most significant threat to five of the nine attributes, while livestock grazing, water projects, and exotic species each were the most significant threat to only one attribute.

The mean significance rating, across all attributes (table 1), was greatest for fire and its management (3.4). This can be considered the most significant threat to the preservation of wilderness character in the Northern Region. Other threats with high mean significance ratings (2.7 to 2.9) were atmospheric pollutants, recreation, and practices on adjacent lands. Even threats with lower ratings—such as livestock grazing, exotic species introductions, mining, and water projects—have the potential to substantially impact wilderness; however, they are relatively limited in Northern Region wilderness. Livestock grazing would be a more significant threat in the southwestern United States, while exotic species introductions would be more significant in the southeastern United States. Threats from atmospheric pollutants and practices on adjacent lands would be more significant in the eastern United States, where wildernesses are typically small and close to urban areas. Water projects are likely to be a more significant threat in proposed Bureau of Land Management wildernesses, which typically do not contain headwaters.

Differences in significance among threats to attributes are greater than differences among the threats themselves. Seven of the nine wilderness attributes were considered the attribute most significantly impacted by at least one potential threat. Geological and cultural features were not the most significantly impacted attribute for any threat. Aquatic systems was considered the attribute most threatened by six different threats, and vegetation was considered the attribute most threatened by five different threats.

Potential Threats

Attributes of Wilderness Character	Recreation	Livestock	Mining	Fire	Exotic species	Water projects	Atmospheric pollutants	Adjacent lands	Other
Air	1	1	1	2	1	1	4	3	
Aquatic systems	4	3	3	4	4	3	4	3	
Rock/landforms	1	2	2	1	1	2	1	1	
Soils	3	3	2	5	2	2	4	2	
Vegetation	3	3	2	5	4	3	4	2	
Animals	4	2	2	4	3	2	2	4	
Ecosystems/landscapes	2	3	2	5	3	2	4	5	
Cultural resources	3	2	2	2	1	1	1	1	
Wilderness experiences	4	3	2	3	2	2	2	3	

Figure 12—Significance ratings for the impacts of each potential threat on each wilderness attribute, for wildernesses in the Forest Service's Northern Region. Ratings range from 1 (low) to 5 (high).

Table 1—Significance of and knowledge about eight potential threats to wilderness in the Northern Region[1]

Threat	Significance rating	Knowledge rating	Research gap index
Fire	3.4	3.5	3.0
Atmospheric pollutants	2.9	3.1	2.8
Recreation	2.8	3.1	2.8
Practices on adjacent lands	2.7	2.9	2.8
Livestock Grazing	2.4	3.5	2.1
Exotic species	2.3	2.5	2.6
Mineral activities	2.1	2.9	1.4
Water projects	2.0	3.1	1.4

[1]Ratings are between 1 (low) and 5 (high) and are mean ratings for the nine individual wilderness attributes. Impacts given a significance rating of 1 were excluded from the mean knowledge ratings. The research gap index is the mean research priority rating, between 1 (low) and 5 (high) for the nine attributes.

The mean significance rating for wilderness attributes, considering all threats (table 2), was greatest for aquatic systems (3.5). If aquatic systems are the most threatened of wilderness attributes, an immediate shift in priorities is needed. Most attention is being given to management of terrestrial systems in wilderness. Vegetation and ecosystems/landscapes also had high significance ratings of 3.3.

Research Gaps Concerning Threats to Northern Region Wilderness

By comparing significance and knowledge ratings, relative priorities can be assigned to each impact concerning the need for further research (fig. 13). I assigned a low priority to impacts with significance ratings of 2 or less, regardless of knowledge levels. I assigned moderate priority to those impacts with significance ratings of at least 3 and knowledge ratings at least as high as their significance ratings. Finally, I assigned high priority to impacts with significance ratings of at least 3 and knowledge ratings lower than their significance ratings. Of the 72 impacts (cells in the matrix), 37 (51 percent) are low priority, 21 (29 percent) are moderate priority, and 14 (19 percent) are high priority. While the high-priority impacts are in most immediate need of further research, all of the moderate-priority impacts and many of the low-priority impacts also need further study.

To extend this analysis to general conclusions about the relative priority of individual threats and attributes, I calculated a research gap index. I assigned values of 1 (low priority), 3 (moderate priority), or 5 (high priority) to each cell in the matrix. The research gap index is simply the mean of these rankings across all threats or across all attributes. This analysis suggests that

Table 2—Significance of and knowledge about threats to nine attributes of wilderness in the Northern Region[1]

Threat	Significance rating	Knowledge rating	Research gap index
Aquatic systems	3.5	3.5	3.5
Ecosystems/landscapes	3.3	2.4	3.3
Vegetation	3.3	3.8	2.8
Soils	2.9	3.5	2.5
Animals	2.9	2.6	2.8
Wilderness experiences	2.8	2.9	2.8
Air	1.8	3.7	1.5
Cultural resources	1.6	2.8	1.3
Rock/landforms	1.4	3.0	1.0

[1]Ratings are between 1 (low) and 5 (high) and are mean ratings for eight potential threats. Impacts given a significance rating of 1 were excluded from the mean knowledge ratings. The research gap index is the mean research priority rating, between 1 (low) and 5 (high) for the eight threats.

Figure 13—Research priorities for the impacts of each threat on each wilderness attribute, for wilderness in the Forest Service's Northern Region. Low-priority impacts had a significance rating of 2 or less, regardless of knowledge. Medium-priority impacts had a significance rating of at least 3 and a knowledge rating at least as high as its significance rating. High-priority impacts had a significance rating of at least 3 and a knowledge rating lower than the significance rating.

fire and its management is the potential threat most in need of further research in the Northern Region (table 1). Threats with moderately large research gaps are exotic species introductions, practices on adjacent lands, atmospheric pollutants, and recreation. Threats that are the lowest priorities for further research in the Northern Region are mineral activities, livestock grazing, and water projects.

The attributes most in need of further study are aquatic systems and ecosystems/landscapes (table 2). Attributes with moderately large research gaps are wilderness experience opportunities, animals, vegetation, and soils. The attributes that are the lowest priorities for further research in the Northern Region are cultural resources, rock/landforms, and air. Again, even these lowest priorities are so poorly understood that more research is warranted.

CONCLUSIONS

This matrix of potential threats to attributes of wilderness character can be a useful tool to wilderness managers. It can be used to evaluate the significance of threats to wilderness and to set management priorities. It can be used to identify critical research gaps. It also can be used to identify the types of impacts that need to be monitored. These priorities can be assessed either for individual wildernesses or for larger regions.

In Northern Region wilderness, the most significant threat to wilderness character is the suppression of natural fire. The most threatened wilderness attribute is aquatic systems. The most critical research needs would appear to be research on fire, aquatic systems, and ecosystems and landscape patterns and processes. In other parts of the country and in wilderness managed by other agencies, other threats and attributes will be more important and in more need of study. Each region would profit from assessing threats to wilderness in the manner reported here.

The conclusions reported here are the collective informed judgments of a group of regional experts. The uncertainty of these conclusions reflects the inadequate attention given to wilderness threats and the lack of extensive data. The threats matrix is a conceptual framework that forces us to take a more comprehensive perspective than we have typically taken. This is merely the first step toward a more comprehensive view of wilderness management. That view will be necessary if we are to approach the lofty goals established by the Wilderness Act.

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A comprehensive framework for assessing threats to wilderness is described. The framework is represented as a matrix of potential threats and attributes of wilderness character. Cells in the matrix represent the impacts of threats on each attribute. Potential applications of the matrix are described. An application of the matrix to the wildernesses in the Forest Service's Northern Region (northern Idaho and Montana) suggests that fire management is the most significant threat to those wildernesses and that aquatic systems are the most threatened wilderness attribute.

KEYWORDS: impacts, monitoring, assessment, Idaho, Montana

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